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Dewatering using groundwater modelling in Al-Fustat area, Old Cairo, Egypt

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KEYWORDS

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Abstract The purpose of this study is to find a solution for the groundwater uprising in Al-Fustat area – Old Cairo, Egypt. A 3-D finite Difference Model (Visual MODFLOW-Ver. 3.1) has been used to simulate the impact of different alternative solutions in order to select the best suitable one. The result of geophysical survey, twenty bore holes data, hydro-geological data and satellite images were used to construct and calibrate the numerical model of Al-Fustat city. Finally, the recommended solution is a combination of pumping wells and tile drains. The results of this solution indicate that using pumping rate of 200 m^3/day achieves 2–3 m drawdown which meets the target.

1. Introduction

Al-Fustat (which is in present day "Old Cairo"), was established on the eastern bank of the Nile River at a strategic location. This study focuses on a part of Al-Fustat City which is bounded by polygon shown in Fig. 1. Over the past decades, the exposed stone foundations of Al-Fustat area have deteriorated at an alarming accelerated rate. Consequently, extreme changes in groundwater regime have been detected.

The objective of this study is to present a solution for lowering the groundwater levels in the study area. This solution is considered as an initial stage for restoring Al-Fustat touristic area.

2. Background and problem definition

The study area is considered as a part of the old alluvial plane of the River Nile. Fig. 2 shows a 3D view of topographic feature of the pilot area. Geologic map of the study area (Fig. 3) indicates the presence of the following geologic formations on the study area:

- Middle Eocene formation: this formation contains the deposits of limestone (Mokkatam Formation).
- Quaternary formation: The Holocene of young alluvial deposits which is characterized by silt, clay and fine sand facies.

Obviously, most of Cairo city is built on the surface Nile deposits, intercalated with remnants of the broken parts of old cities. This type of debris could reach to 15 m thick.

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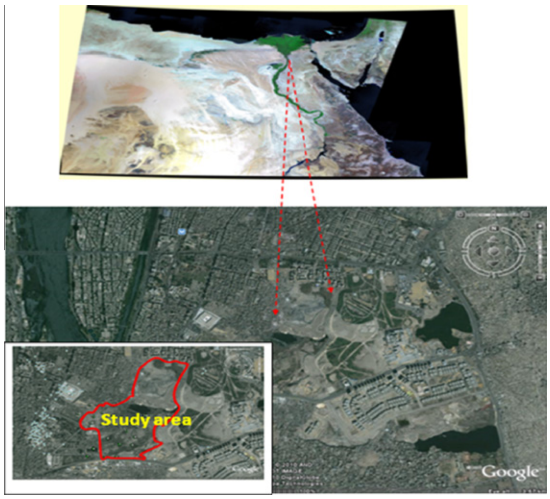

Figure 1 Study area.

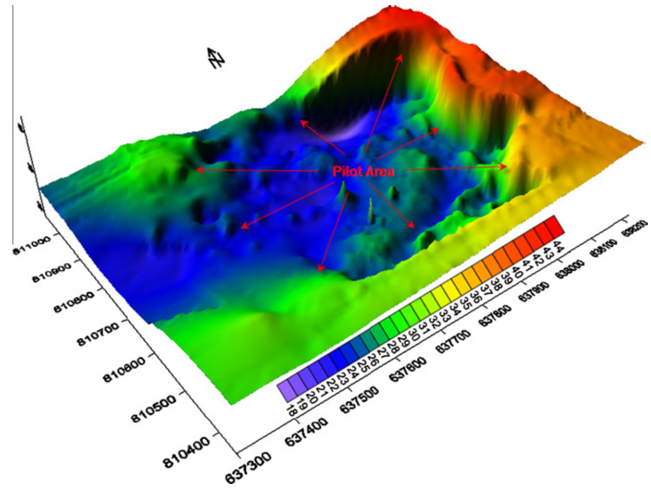

Figure 2 3D topographic feature of the pilot area.

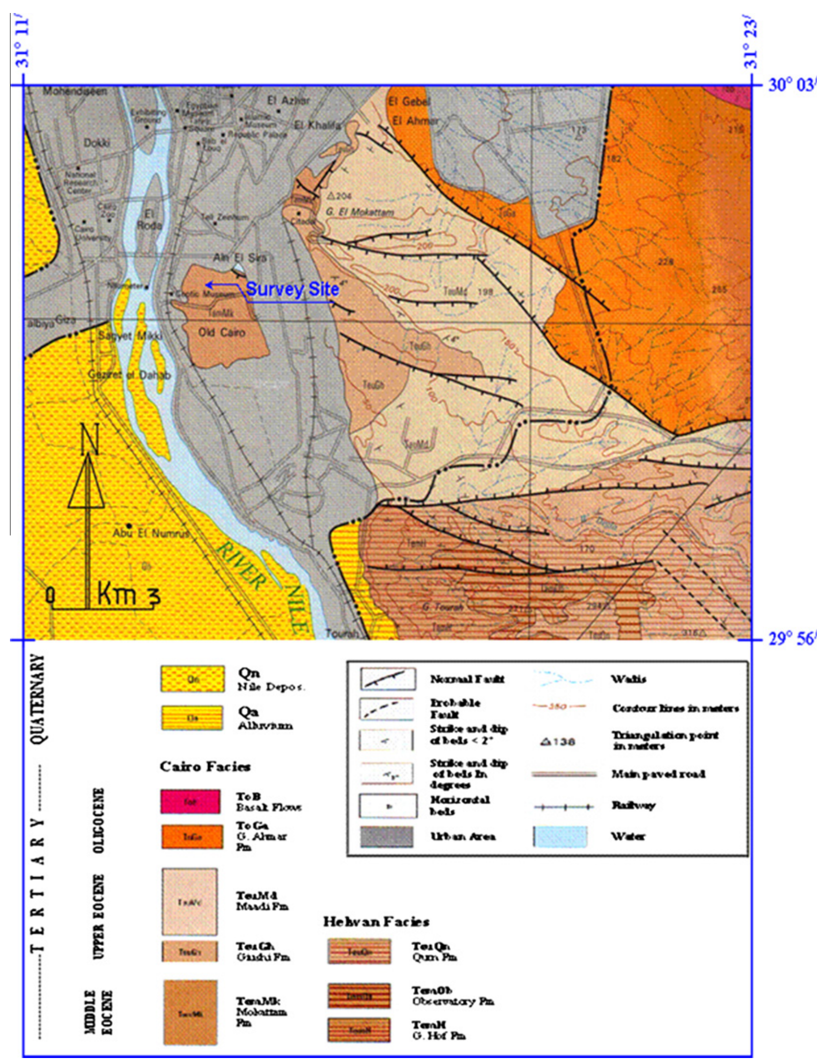

Figure 3 Geological map of the study area (geological survey of Egypt, Cairo – 1983).

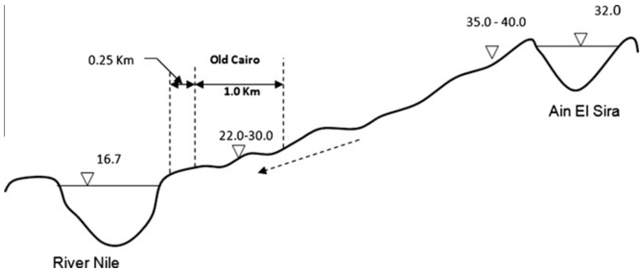

Figure 4 Cross section passing from Ain El-Sira to River Nile.

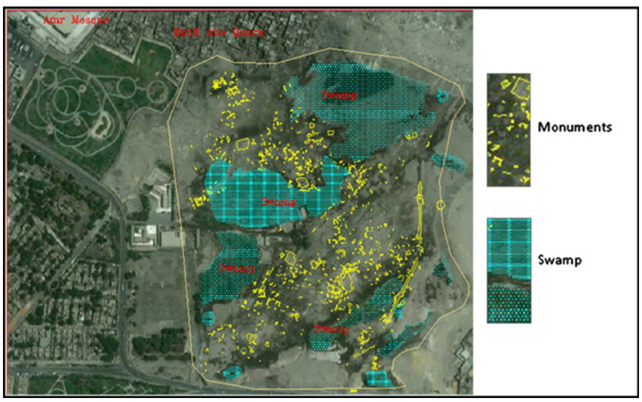

Figure 5 Monuments and swamps distribution of Pilot area.

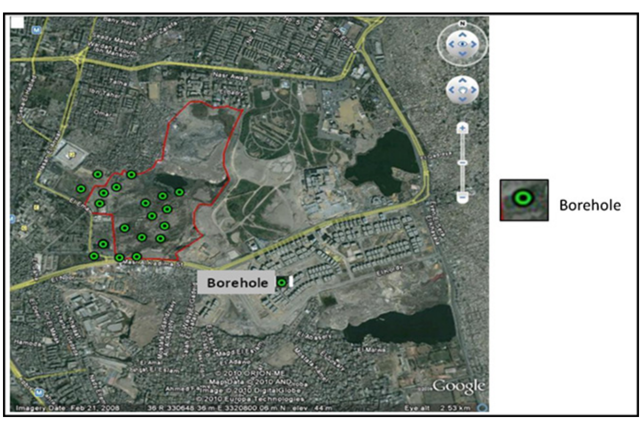

Figure 6 Borehole locations.

2.1. Geologic structures

The area is affected by a series of faults, normal and step faults. NW–SE, NE–SW and E–W are the dominant structural directions as shown in (Fig. 3). Topographic situation of the study area comes as an impact of this structural setting.

2.2. Hydrogeologic background

Many researchers worked on the methods used to protect the archaeological sites in Egypt against groundwater threats. Antoniou [1] and Moselhy [2] threw light on historical background of Al-Fustat city. Hefny [3] and Attalla [4] investigated the problem of groundwater rising in Old Cairo. Abu ElSoud

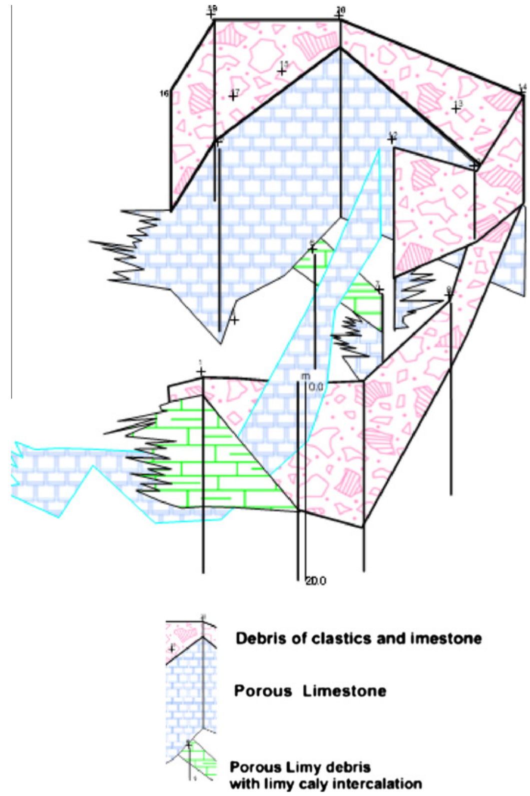

Figure 7 Fence diagram showing the facies sequence for the study area.

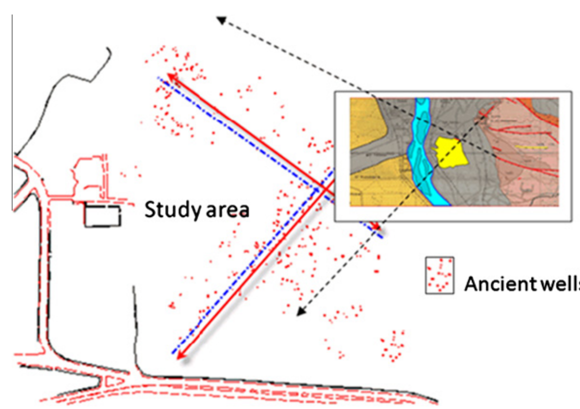

Figure 8 Main directions of existing ancient wells.

Figure 9 Remnant wall and Phragmetis australis plant.

Figure 10 Swamps area.

[5], investigated the environmental relation between the geologic structures and the geomorphological characteristics of New Cairo area (including Al-Fustat city) and its vicinity. MAFEC [6] conducted the geotechnical investigation for the studied area. El-Bahrawy and Hassan [7] used Visual MODFLOW to suggest solution for lowering groundwater levels at archaeological sites in Hawara Pyramid and Kiman Fares, Egypt. Dahlia [8] reviewed the methods used for lowering groundwater levels at archaeological sites in Egypt. Edgar [9] investigated the hydro-geological conditions at the West bank temples in Luxor in order to identify where detailed field data is necessary for the success of a future groundwater model using the computer code MODFLOW, which is an interface to the program GMS (Groundwater Modelling System). A Cross section (Fig. 4) -passing from Ain El-Sira to the east and River Nile to the east- indicates that the Nile is considered as a drain to the study area.

2.3. Field work

2.3.1. Site visit

The site visit aims to specify the features of the study area and its boundaries. From the site visit, it is noticed that the study area is surrounded by hazardous human activities that cause many environmental problems. Hydrogelogical conditions of areas surrounding the monuments had been changed, so the area started to suffer from groundwater rising which caused the formation of some swamps (Fig. 5).

2.3.2. Data collection

Elevation survey works were executed to construct a topographic map for the study area. Also, the locations of the monuments in the area are surveyed as shown in Fig. 5. Geophysical survey using seismic and electromagnetic methods were conducted. Twenty boreholes had been drilled as peizometers. Identification of stratigraphic sequences and monitoring of the groundwater levels are the aim of drilling such boreholes (Fig. 6).

The description of subsurface situation is based on the data of 20 boreholes (20 m deep). Fence diagram illustrates the subsurface sequence of geologic layers (Fig. 7). Depth to water traced on the fence diagram. The diagram shows the vertical and horizontal variation in lithology.

Using the data of geological and geophysical cross sections, the subsurface characteristics are identified. The surface layer consists of debris and limy facies. Also fractured limestone appears in some locations in this layer. Second and third layer are mainly composed of limestone, the third one is less in

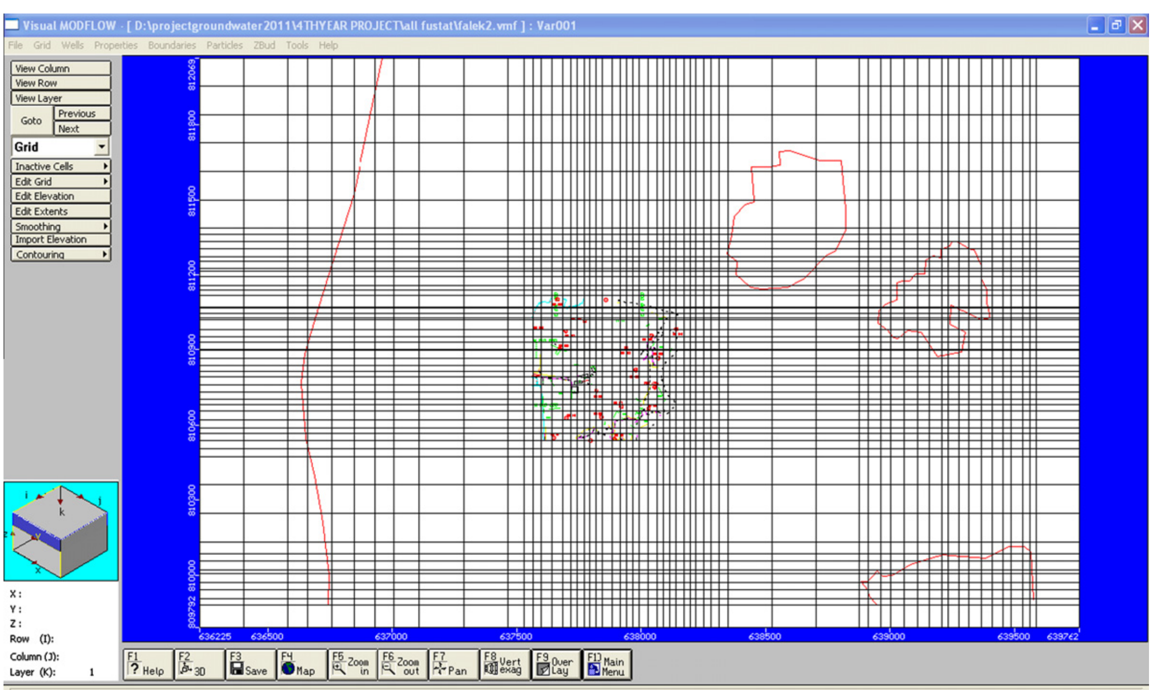

Figure 11 Grid for the study area.

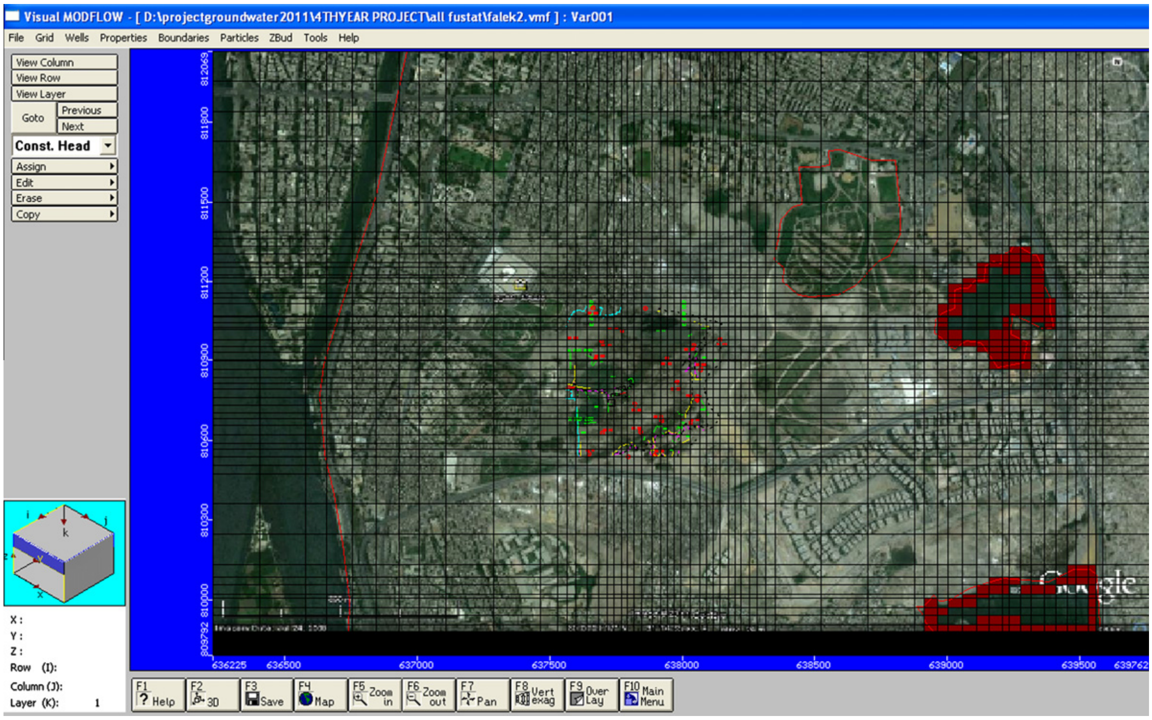

Figure 12 Prescribed head boundary conditions.

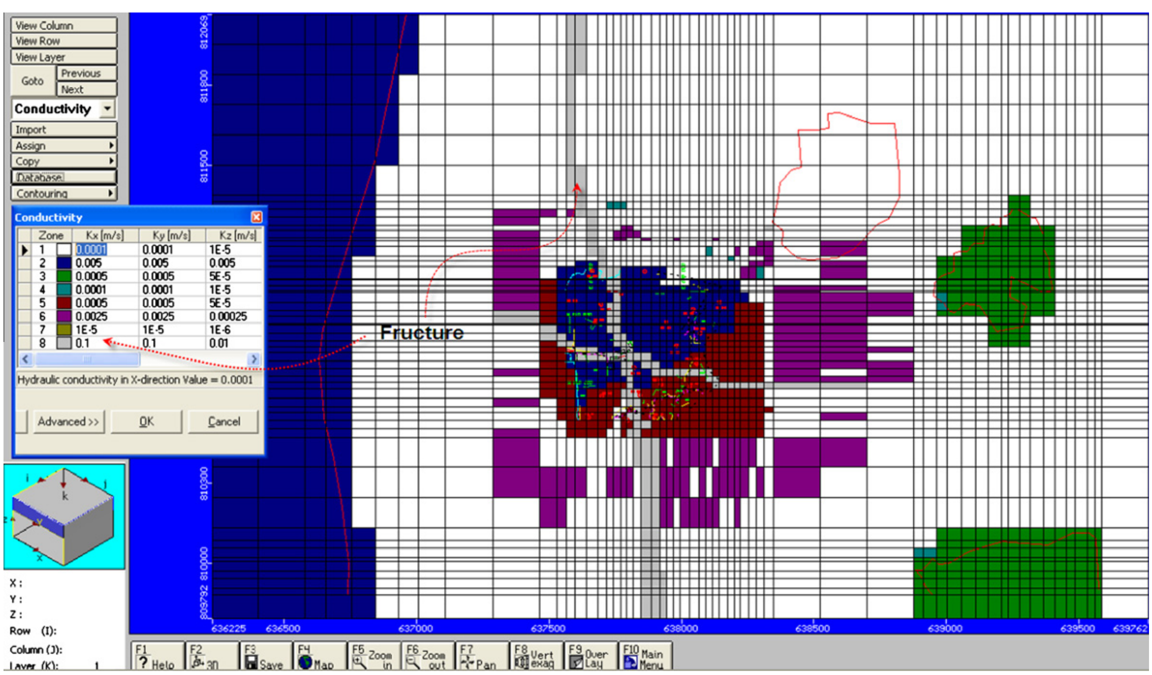

Figure 13 Hydraulic conductivity distribution.

fracturing compared to the second one. Hundreds of ancient wells had been detected in the study area. It is noticed that these wells are drilled in two main directions in horizontal plane as shown in Fig. 8. These directions had been taken into consideration during the model construction.

2.3.3. Problem definition

In last two decades, Al-Fustat area is suffering from uprising of groundwater levels which threatens the monuments of the area. Accordingly, Phragmetis australis plants, water logging and swamps are observed (Figs. 9 and 10).

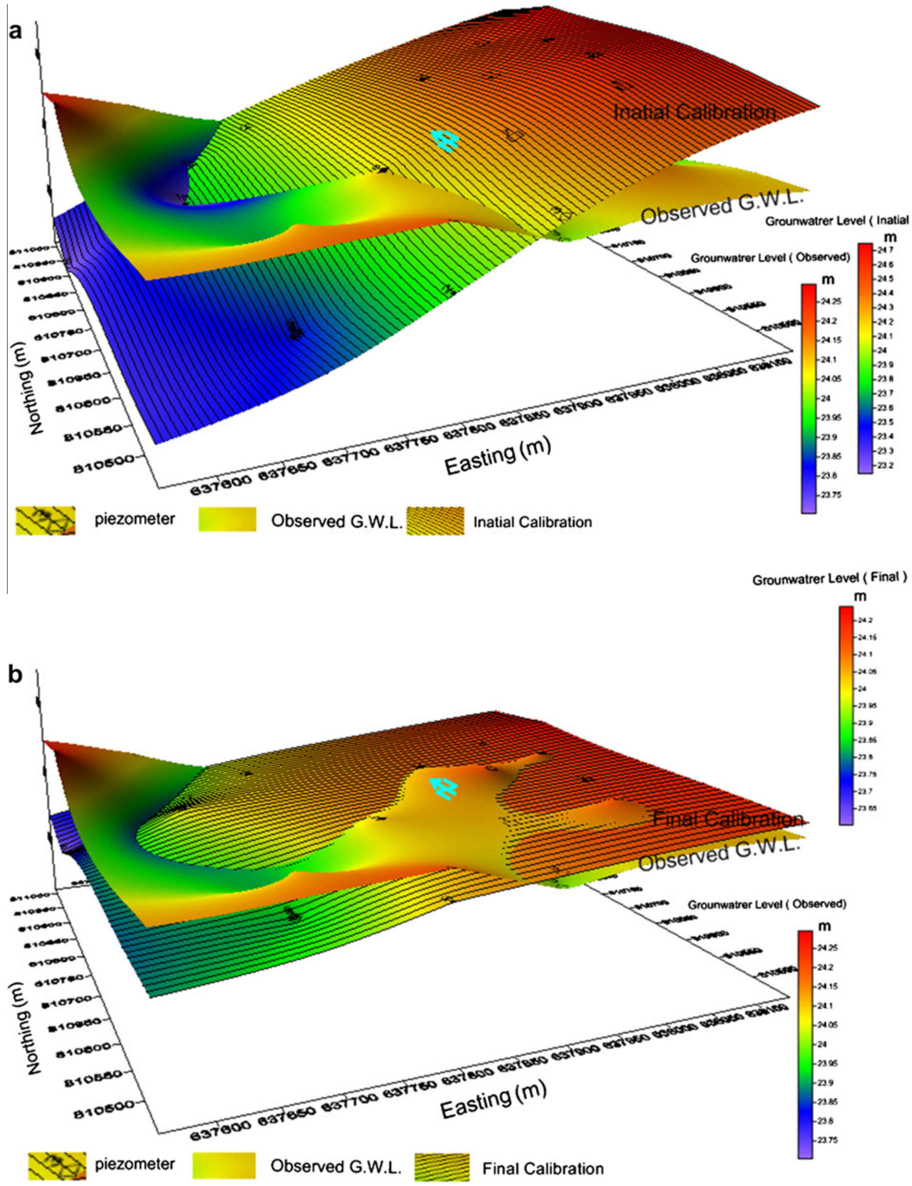

Figure 14 3D view of observed and calculated groundwater level (a) observed and initial calibrated water level , (b)observed and final calibrated water level.

3. Problem simulation using numerical model

3.1. Model construction

The surface geologic, land use, topographic maps and satellite images are used as a guide to assume the hydraulic conductivities for the domain. Geophysical studies output – seismic sections- are used to construct the model in three layers. In general, it is assumed that the first layer has generally the highest hydraulic conductivity.

In this study, three-dimensional groundwater flow is simulated using the Visual MODFLOW. This model has a wide variety of boundary conditions and input options. It depends on the finite difference method in solving the groundwater flow equation numerically. The model is using a 3-dimensional mesh and applying sources/sinks and other model parameters on the nodes and cells.

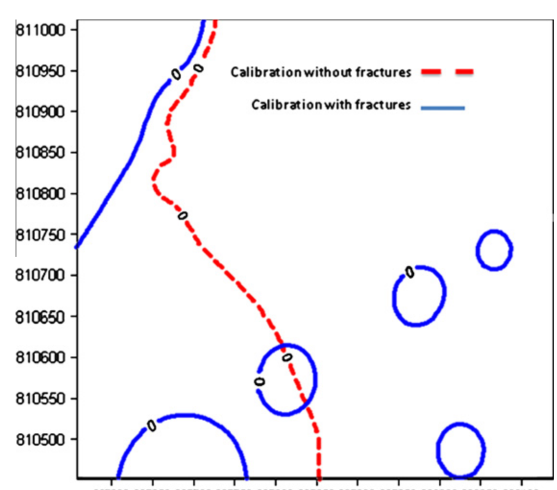

Figure 15 Comparison between zero percentage error distribution in case of calibration with and without fractures.

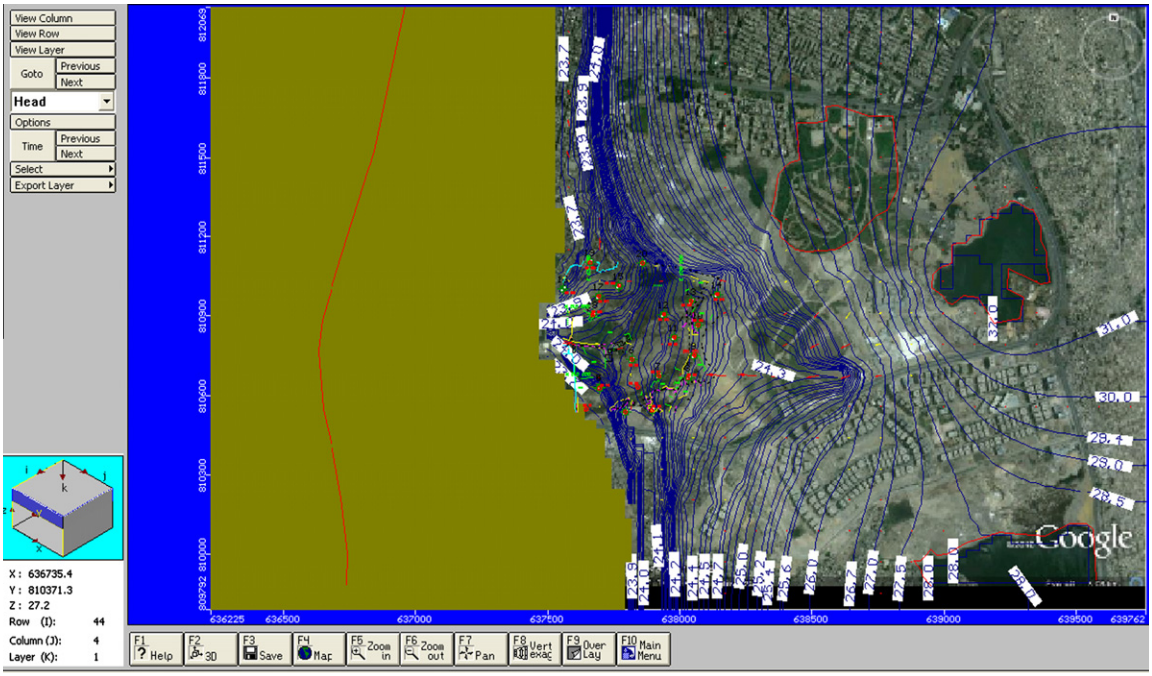

Figure 16 Isolines of potentiometric surface of groundwater (model calibration).

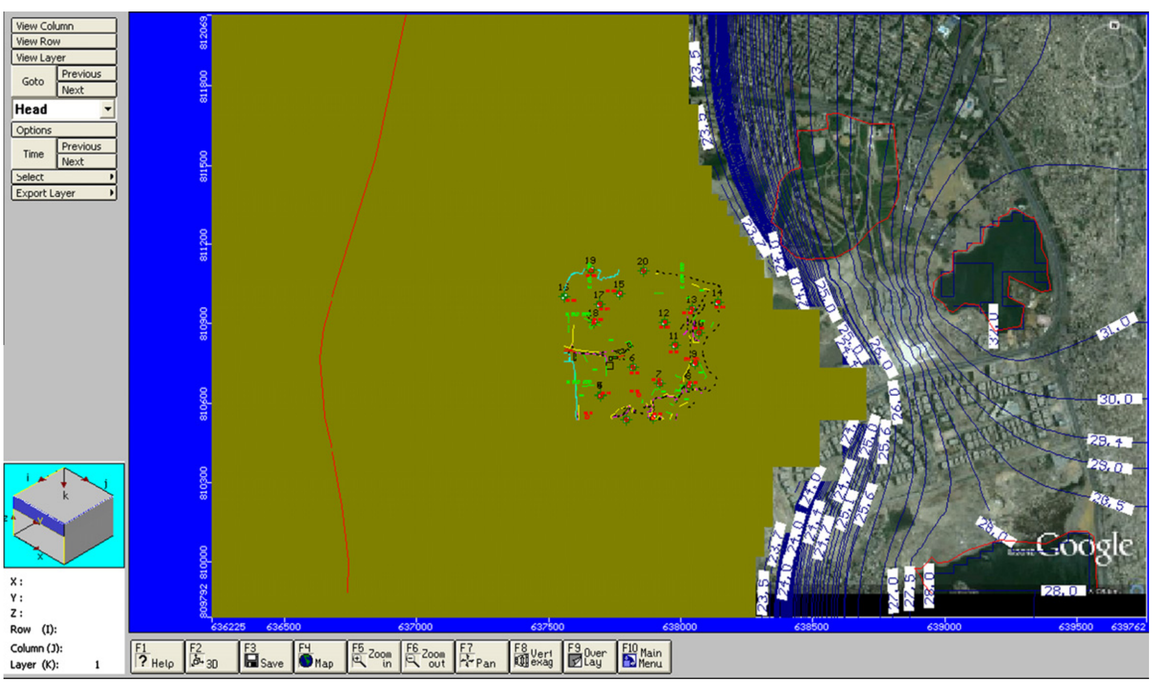

Figure 17 Isolines of potentiometric surface of groundwater after pumping (model application).

The governing equation for the groundwater problem in Al-Fustat area will be simulated under steady state flow as follows:

$$\frac{\partial}{\partial x}\left(K_x h \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y h \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z h \frac{\partial h}{\partial z}\right) \pm Q = 0$$

In order to solve this equation the boundary conditions should be described as follows:

$$Kh\frac{\partial h}{\partial n} = W_1(x,y) \quad (x,y) \text{ at } \partial\Omega_1$$
$$h = W_2(x,y) \quad (x,y) \text{ at } \partial\Omega_2$$

where h is the head; K_x, K_y, K_Z is hydraulic conductivity in x- y- and z- directions respectively; $\pm Q$ is Sink (-sign) or source (+sign) function; W_1, W_2 is known function; $\frac{\partial h}{\partial n}$ is normal derivative and $\partial\Omega$ is the boundary of the aquifer.

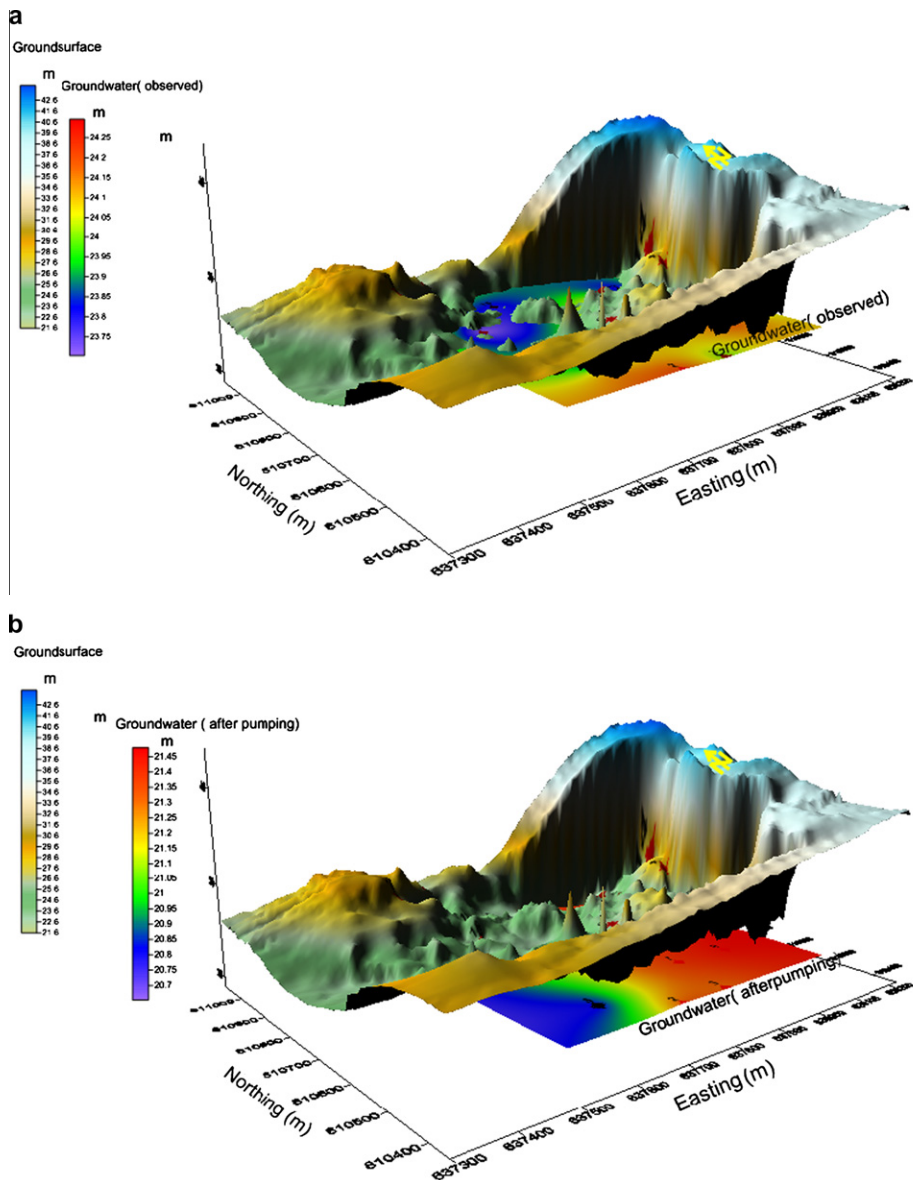

Figure 18 3D view of groundwater levels at the proposed wells before and after implementing the solution.

3.2. Development of the mesh and boundary conditions

As shown in (Fig. 11) the grid covers an area about 2000 m by 3000 m. The mesh has variable cell size, small where the wells are located and coarse elsewhere. No distributed flow into the system has been considered since infiltration from precipitation is negligible. Flow in/out of the system is from constant heads at eastern boundary; Ain El Sira lakes, west boundary; River Nile (Fig. 12). Elsewhere the boundary conditions are no flow.

3.3. Numerical model calibration

To ensure the ability of the model to simulate a solution, the model should be calibrated using the available field data. The numerical model calibration becomes a tool to reflect the real situation of the study Soliman [10], Lee and Swancar [11] and Nelson [12]. The calibration process has been conducted by comparing the model result with the observed data.

Many trials have been carried out to meet the observed data. In initial trials, it is assumed that the domain has no fractures; consequently the model gives low confidence results. By considering fractures of the geologic formation, the calibration gets accelerated and results are more reliable. The hydraulic conductivities distribution considering fractures is shown in Fig. 13. Fig. 14 shows the comparison between the observed data and the computed values in initial and final calibration. The comparison between percentage error of results in case of initial and final calibration is illustrated in Fig. 15. As illustrated in Fig. 15, the zero error line in case of initial calibration divides the study area into two zones. On the other hand, in the case of final calibration, the zero error lines almost cover the study area. It is meant that the error becomes distributed all over the area after taking the fractures into consideration.

4. Problem solution

The most effective solution of ground water uprising is dewatering Cloos [13]. The main objective of this study is to find an effective method for lowering the groundwater level by 2–3 m in average .The recommended solution consists of an interceptor (tile drain that is located at the boundary of the area) to cut the recharge water coming from the places surrounding the study area (Fustat garden, Fustat-residential random; Izbat Abu Karn and Batn el Baqar). Also the solution includes dewatering wells to pump out the groundwater that moves through cracks and fractures rocks. These wells are to be used to reduce groundwater level to desired level in the whole studying area. The solution is simulated by the model and the number of wells is specified according to the target water level. The recommended wells' numbers as a result of numerical model are 20 wells (same location of boreholes) and having rate of 200 m^3/day.

Fig. 16 presents the calibrated head value which comes in consistence with the present situation. The final results of the solution are illustrated in Fig. 17. Fig. 18 shows the groundwater levels before and after implementing the solution at the proposed pumping wells. It is noticed that the groundwater levels is lowered by 2.5 m in average.

5. Conclusions and recommendations

The sources of groundwater in the region are from the irrigation water of green areas (Fustat Garden and Club area) that lie in eastern of the study area, Wastewater from tranches in the slums of regions (Abu Karn and Batn ElBaqar) located north west of the study area, uprising groundwater flow from deep aquifers through fissures and cracks in the rocks of the study area and leakage water from sewage system extended South from residential areas.

It is concluded that the reasons of water table rise in the area are:

- The upward flow from the deep aquifer of Nubian sandstone through the fractured limestone aquifer. This flow causes scattered springs (lakes) such as Ain El Sira, Ain Helwan and Ain Musa (Al Mokkatum).
- Horizontal component for groundwater flow through the predominant fracture system of limestone, specially, at the eastern part of the study area, where Ain El Sira lake is present. Additionally, the leakage from the irrigation water and ponds existing in Al Fustat Garden.
- Leakage from the closed slums.

By considering fractures of the geologic formation, the calibration gets accelerated and results are more confident. The proposed solution which is a combination of pumping wells with pumping rate of 200 m^3/day and tile drains, has been achieved to lower the groundwater level by 2.5 m in average. for the study area to realize drying condition to enable the restoration works in Al Fustat city.

It is recommended to establish a monitoring system to keep the groundwater level in the study area under control. The pumped water is recommended to be managed; it can be used for irrigation in the landscaping of Al-Fustat garden. Detailed study is recommended for the use of pumped water for Balneotherapy.

References

[1] Antoniou J, Bianca S, EL-Hakim Sh, Lewcock R, Welbank M. The conservation of the old City of Cairo. Paris: United Nations Educational, Scientific and Cultural Organization; 1985.

[2] Moselhy SA. Economic and social life in Al Fustat in Fatimid period. MA thesis, Al Azhar University, Faculty of Humanity studies, Cairo, Egypt; 1989 (in Arabic).

[3] Kamal Hefny. Study of groundwater in the province of Greater Cairo: First Phase final report. Research Institute for Groundwater; 1989.

[4] Attalla M. Ground water investigation at tri-religion monumental region of old Cairo. Rotterdam: Engineering Geology and the Environmental; 1997.

[5] Abou El-Saoud W. Geoenvironmental studies on New Cairo area and its vicinity, Egypt, using remote sensing data and geographic information systems. MSc Thesis, Al-Azhar University, Cairo, Egypt; 2006.

[6] MAFEC. Restoration, development project and lowering of groundwater – Al Fustat Area-Old Cairo. Construction and geotechnical consultancy; 2010.

[7] El-Bahrawy AN, Hassan AA. Protection of the Egyptian monuments from groundwater, case study: Hawara Pyramid and Kiman Fares. Special Issue J Environ Sci 2003;6(4):1441–51.

[8] Hassan Dahlia S. Review of methods used for lowering groundwater levels at archaeological sites, Egypt. Master thesis, Department of Water Resources, Faculty of Engineering, Lund University; 2006.

[9] Edgar Herbas Campos. A groundwater flow model for water related damages on historic monuments – case study West Luxor, Egypt division of water resources engineering, department of building and environmental technology. Lund University; 2009.

[10] Soliman MM. Groundwater model for the Nubian aquifers in the north eastern of Africa Internal report. Research Institute for Groundwater, Cairo; 1987.

[11] Lee, Swancar. Flow in fractured porous media. Water Resources Res, vol. 13; 1994.

[12] Nelson Ronald A. Geologic analysis of natural fractured reservoirs. Butterworth–Heinemann, Elsevier; 2001.

[13] Cloos Mark. Landward-dipping reflectors in accretionary wedges: active dewatering conduits. Geol Soc Am 1984;12(9):519–22.

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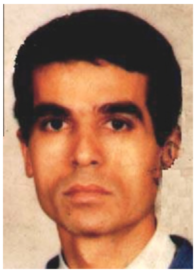

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